DEVELOPMENT OF POWER FACTOR CORRECTION USING BOOST CONVERTER CIRCUIT

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To my father and mother...

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ABSTRACT

This project describes on developed of a system that can control current by using Texas Instruments microcontroller with Code Compressor Studio software. The type of controller used is C2000 Microcontroller (Texas Instrument TMS320F28) for current feedback loop application. The connection between PC as the software for Code Compressor Studio software (CCS), Pulse Width Modulation (PWM), Texas Instrument (interface), gate driver, power factor correction circuit in boost circuit topology and rectifier circuit, load and sensor are the main parts in this project. Texas Instrument works as the interface communication with MATLAB SIMULINK 2015a to the power factor correction system. In order to control the triggering of the MOSFETs in the Power Factor Correction (PFC), the Pulse Width Modulation (PWM) is needed from MATLAB SIMULINK that has been applied in this project. The main objective in this project is to control the current output by using microcontroller and to detect the load current in order to have the closed loop feedback. By designing the rectifier and the boost circuit in MATLAB simulation is the first part of the project, which gives Total Harmonic Distortion in opened loop 23.86 % and meanwhile for about 17.66 % in closed based. At the same time the hardware part has also been assemble. The current controller loop has been designed according to mathematical equations which is achieved the results of efficiency and stability in output voltage and the input current of the source. With 22 V AC voltage input the obtained output of the rectifier circuit voltage is at 21.2 V DC voltage with 0.139 mA current. Meanwhile the boost circuit boosted the output voltage to 31.6 V DC voltage with 1.05 mA amount of current. The project has been accomplished and achieved all the objectives successfully.

ABSTRAK

Projek ini menerangkan tentang dibangunkan sistem yang boleh mengawal semasa dengan menggunakan mikropengawal Instrumen Texas dengan perisian Kod Kompresor Studio. Jenis pengawal yang digunakan ialah C2000 Microcontroller (Texas Instrument TMS320F28) untuk aplikasi gelung maklum balas semasa. Sambungan antara PC sebagai perisian untuk memantau perisian Compressor Studio Studio (CCS), Pulse Width Modulation (PWM), Texas Instrument (antara muka), pemandu pintu, litar pembetulan faktor kuasa dalam meningkatkan litar topologi dan litar penerus, beban dan sensor adalah bahagian utama dalam projek ini. Instrumen Texas berfungsi sebagai komunikasi antara muka dengan MATLAB SIMULINK 2015a kepada sistem pembetulan faktor kuasa. Untuk mengawal pencetus MOSFET dalam Pembetulan Faktor Kekuatan (PFC), Modulasi Lebar Pulse (PWM) diperlukan daripada MATLAB SIMULINK yang telah digunakan dalam projek ini. Objektif utama dalam projek ini adalah untuk mengawal output semasa dengan menggunakan mikrokontroler dan untuk mengesan beban semasa untuk mempunyai maklum balas gelung tertutup. Direka penerus dan litar rangsangan dalam simulasi MATLAB adalah bahagian pertama projek, dan ia memberikan Penyelewengan Harmonik Total dalam gelung dibuka 23.86% sementara itu untuk kira-kira 17.66% dalam tertutup berdasarkan hasil yang diperoleh daripada bahagian simulasi. Pada masa yang sama bahagian perkakasan juga telah ditentukan dan direka. Gelung pengawal semasa telah direka mengikut persamaan matematik yang dicapai hasil kecekapan dan kestabilan voltan keluaran dan arus input sumber. Dengan 22 input voltan AC output yang diperolehi daripada voltan litar penerus adalah pada voltan 21.2 DC dengan arus 0.139 mA. Sementara itu litar rangsangan menaikkan voltan keluaran ke voltan 31.6 DC dengan jumlah semasa 1.05 mA. Projek ini telah dicapai dan mencapai semua matlamat yang berjaya.

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LIST OF SYMBOLS AND ABBREVIATIONS

AC	-	Alternating Current
C	-	Capacitor
D	-	Derivative
DC	-	Direct Current
D	-	Duty Cycle
I	-	Integral
F	-	Frequency
Ki	-	Integral Controller Gain
Kp	-	Proportional Controller Gain
IGBT	-	Insulated Gate Bipolar Transistor
PFC	-	Power Factor Correction
TI	-	Texas Instrument
Vs	-	Voltage Source
MATLAB	-	Matrix laboratory
MOSFET	-	Metal-Oxide-Semiconductor Field-Effect Transistor
P	-	Proportional
PID	-	Proportional Integral Derivative Controller
PWM	-	Pulse Width Modulation
V	-	Volt
μP	-	Microprocessor
μC	-	Microcontroller
R	-	Resistor
THD	-	Total Harmonic Distortion
L	-	Inductor

CHAPTER 1

INTRODUCTION

1.1 Project Background

Power quality has become a critical issue in industries and to sensitive load centers. Nowadays, power electronic appliances are used widely in industrial, commercial and consumer environment. These appliances create a lot of power quality problems in power system. The problems of low power factor, spikes, electrical noise, harmonic distortion are some of the common power quality problems. The main issues that affect the quality of voltage and current waveforms are presence of harmonics and low power factor in power system. A circuit topology that can improve Power Factor (PF) is essential especially for nonlinear loads [1].

Nonlinear loads usually create harmonics and low power factor and it will distort the sinusoidal input current waveform to some other form. The presence of harmonics in both current and voltage is viewed as infection affecting the operation of power systems. Harmonics can cause malfunction of sensitive equipment’s including overheating of electrical equipment’s and wiring and reduced power factor. High levels of power system harmonics can create voltage distortion and reductions in ac source efficiency [2].

Power factor correction (PFC) method is used to improve power factor using suitable circuit topologies. A variety of circuit topologies and control methods have been developed for the harmonic mitigation in power factor correction (PFC) application. The objective of power factor correction circuit is to make input current of the power supply behave like purely resistive load. There are two methods of Power factor correction. They are passive power factor correction method and active power factor correction method.

As shown in Figure 1.1. It is the block diagram of the project. The block diagram contents of PFC boost converter and the rectifier circuit which is non-linear load. This project uses a boost converter as power factor correction method for improving the power factor and reducing the current harmonics using conventional controller. The work initially involves design of the rectifier and the PFC circuit and then analyzing of the source current behavior. All the simulation works are done by using MATLAB Simulink and analyzing have obtained results. The simulation results obtained from the circuit design. It is going to be as reference and guidance for fabricated the hardware experiment with low cost microcontroller with taking care of the results must be like the simulated results.

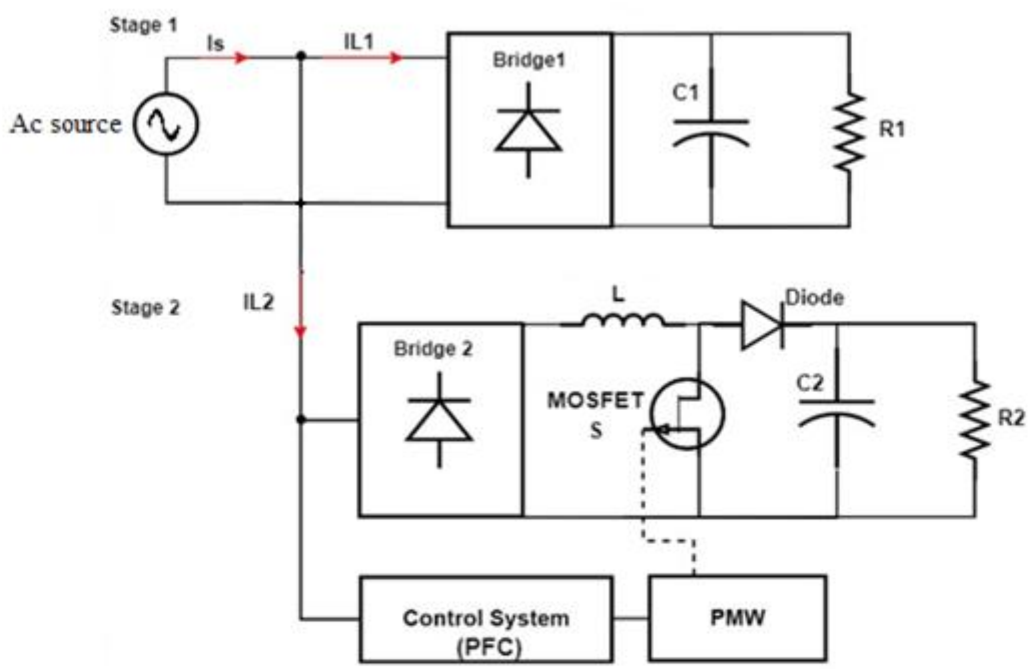

Figure 1.1: Block Diagram of the Project

1.2 Problem Statement

Today's electric power produced or generated by most of the utilities is dispersed to the consumer in the form of AC voltage at 50Hz frequency. But all the power electronic converters are exhibiting to increasing quantities of loads that are nonlinear loads. The nonlinear loads can inject distorted currents in the source network when connected the power systems. As a result, it generates harmonic (nonsinusoidal currents). Harmonic voltages and currents are caused by non-linear loads such as variable speed drives (VSD), uninterruptible power supplies (UPS), low energy lighting and switched mode power supplies in devices such as personal computers. Non-linear loads generate electricity harmonics by drawing current in abrupt short pulses, rather than in smooth sinusoidal, introducing currents of additional frequencies which are reflected back into the system, distorting the AC waveform [3].

This problem will make disturbance to the sinusoidal waveform power system. Therefore, any sorts of loads that connected to the same source will be distorted by the harmonic carried by supply and harmonic. By referring to these problems, a harmonic reduction will be solved by mitigation technique that been developed so that it can reduce harmonic in electrical system. Therefore, the Proportional Integral (PI) controller with PFC boost circuit will be used, due to major effect on the ability of the reducing harmonics.

1.3 Project Objectives

The aim of this project is to improve the input source quality based on the following objectives.

(i) To design the PI controller modelling for a microcontroller in order to minimizing the harmonics distortion at the nonlinear load using current control feedback loop.

(ii) To simulate a model circuit of Power Factor Correction using boost converter.

(iii) To assemble the hardware experiment according to the analysis and the simulation obtained.

1.4 Scope of the Project

The project involved stimulation by MATLAB Simulink and Code Composer Studio software for running the controller target, with design boost circuit PFC (power factor correction) and PI controller based on the current control loop.

The scope of the project has been set as below so the area for the proposed as below.

(i) The power factor correction has been designed in boost converter circuit topology.

(ii) The current controller is used to compensate current for the source.

(iii) The controller and PFC designed are used Simulink in MATLAB software.

(iv) The rectifier with 24V,1A source used as the input source with resistive nonlinear load.

(v) The final system developed in hardware model in order to see the effect of the controller.

(vi) The system configuration is based on nonlinear load with resistive load of 100k ohm that will be connected without and with PFC condition.

(vii) The DC motor and lamp were used as an external load to draw more current source.

CHAPTER 2

LITERATURE REVIEW

Power Factor Correction is the process of maximizing the efficiency of an electrical system to deliver the most possible power as active power. The benefits of power factor correction include significant cost savings and environmental benefits through improved energy efficiency and reduction in electricity consumption throughout the power system. This part of the project will cover the type of Power Factor Correction and the entire requirement for designing the model.

2.1 Power Factor Correction Techniques

Power Factor (PF) is a measure of how effectively incoming power is used in the electrical system and is defined as the ratio of Real to Apparent total power. Real Power is the power that powers the equipment and performs useful. Reactive Power is required by some equipment example transformers, motors and relays to produce a magnetic field for operation and it does not perform any real work. The actual amount of power being used, or dissipated, in a circuit is called true power. It is measured in watts and is symbolized mathematically by the capital letter P. True power is a function of the circuit's dissipative elements, such as resistances [4]. Apparent Power is the vector sum of Real and Reactive Power and corresponds to the total power required to produce the equivalent amount of real power for the load. The Figure 2.1 summarized the relation of the powers.

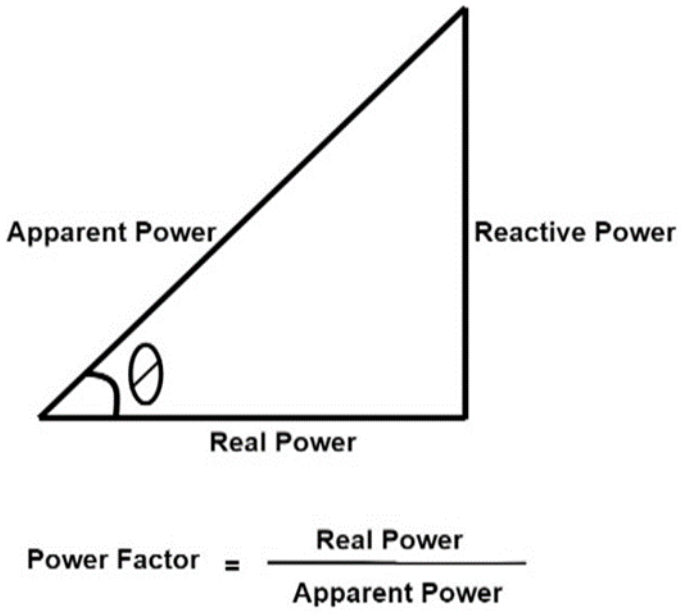

Figure 2.1: Power Factor Triangle

Power factor correction may be required where a system has a power factor of less than 90% (or 0.9). A poor power factor can contribute to equipment instability and failure, as well as significantly higher than necessary energy costs since it means that more current is required to perform the same amount of work, Figure 2.2 shows the effect of the poor power factor which is cause nonlinear voltage and current.

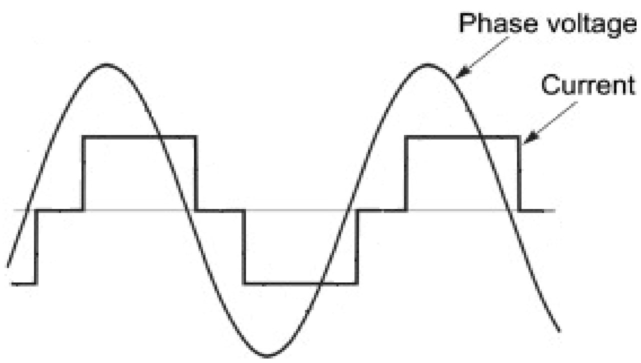

Figure 2.2: Poor Power Factor

By optimizing and improving the power factor, power quality is improved, reducing the load on the electricity system. Figure 2.3 shows the optimizing of the power factor to the system leading to make it nearly linear.

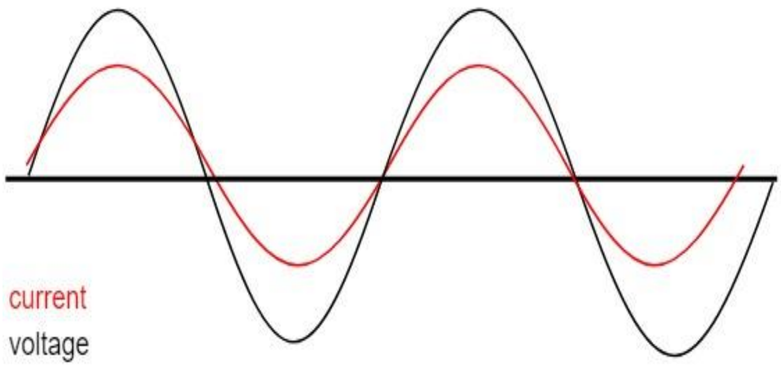

Figure 2.3: Optimize Power Factor

2.2 Types of Power Factor Correction Techniques

Power factor correction (PFC) is used to avoid input current harmonics, thereby minimizing interference with other devices being powered from the same source. The kind of the source must be considered on the method of the PFC correction; hence it is necessary to use suitable power factor correction techniques to counteract the distortion and to improve the power factor. this project is going to use single phase for the supply and the suitable types for that can be shown in Figure 2.4.

Power factor correction topologies can be classified into:

a) Passive Power Factor correction

b) Active Power Factor Correction

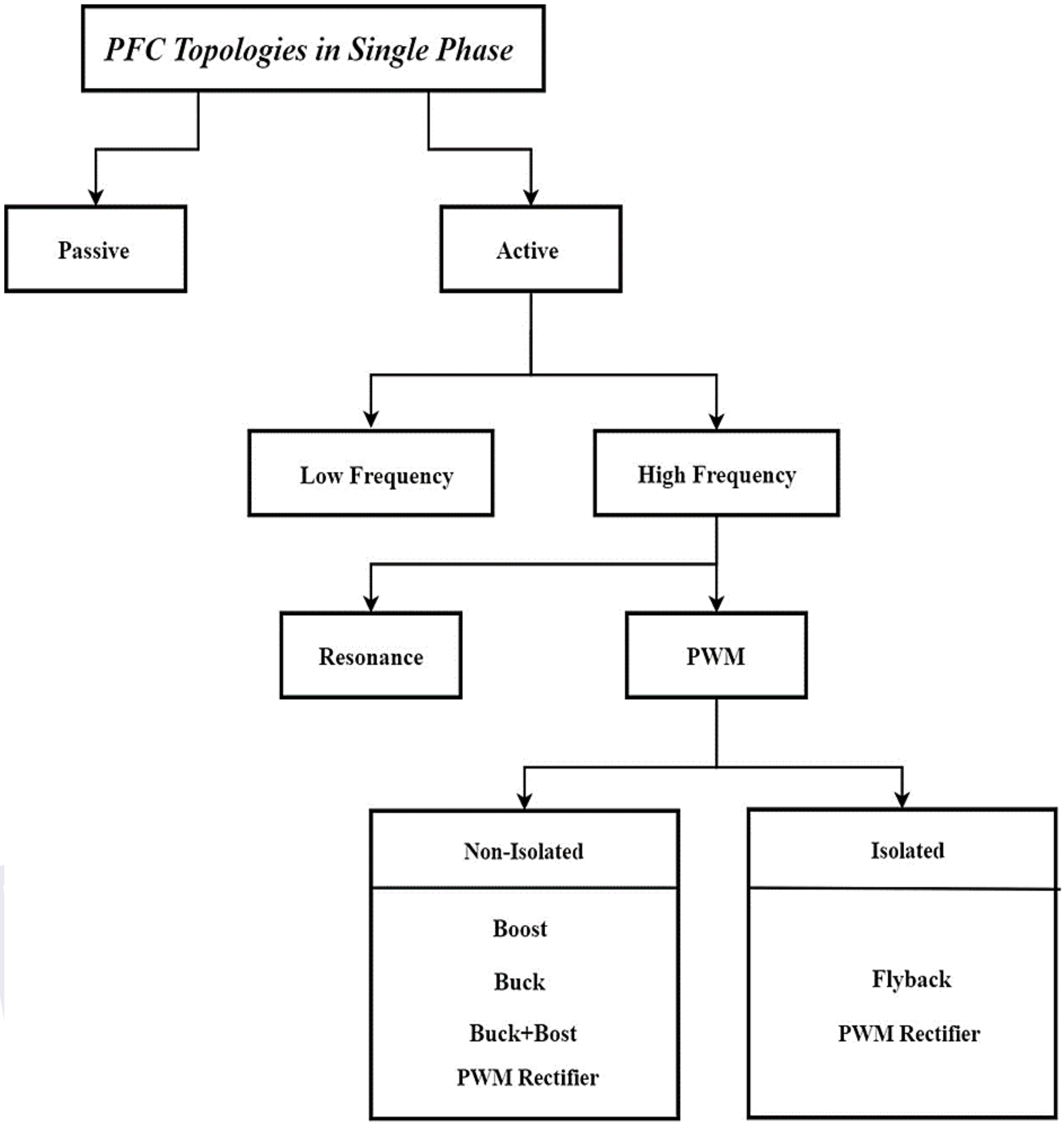

Figure 2.4: PFC Topologies

2.2.1 Passive Power Factor Correction

Passive power factor is one of the techniques for reducing the distortion that caused by harmonics, harmonics can be controlled by adding inductors and capacitors at line frequency 50 or 60 Hz. This method has several of disadvantages. They require large value high current inductors which are expensive and bulky. Poor power factor compared with active schemes [5]. A passive PFC circuit requires only a few components to increase efficiency, but they are large due to operating at the line power frequency.

Passive PFC technique results in lower PF than active PFC technique. Therefore, passive PFC technique is less attractive when priority is given to optimizing the use of the wall plug's volt-ampere capacity rather than just meeting the agency standards [5]. There many of passive power factor correction arrangements techniques one of them as shown below Figure 2.5. L_s is the source inductor , L_f is the inductor filter with C_1 which is a capacitor and C_2 is the load capacitor , D_1, D_2, D_3, D_4 are the rectifier diodes as shown in Figure 2.5.

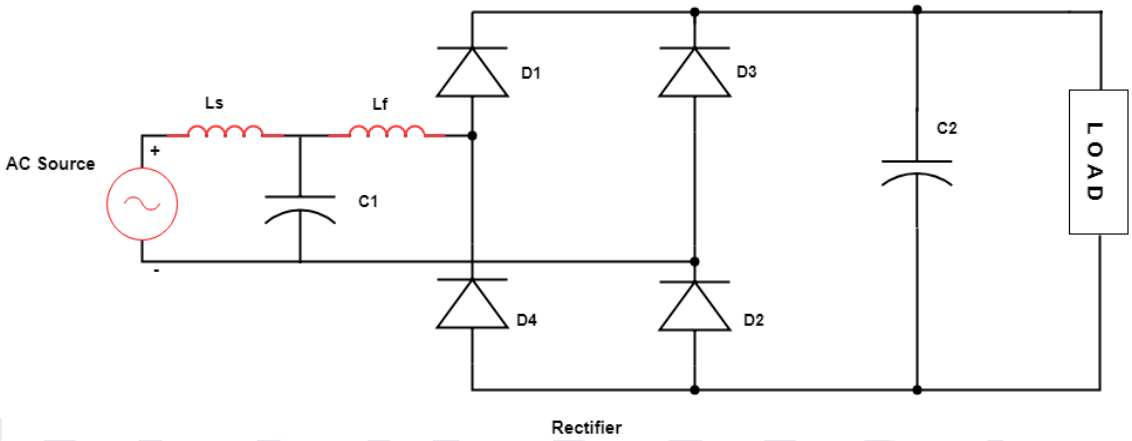

Figure 2.5: Passive Power Factor

2.2.2 Active Power Factor Correction

The active PFC technique, which involves the shaping of the line current using switching devices such as MOSFETs metal oxide semiconductor field effect transistors and IGBTs insulated gate bipolar junction transistors is a result of advances in power semiconductor devices and microelectronics.

For achieving good input current waveform shaping using active techniques, typically the switching frequency should be at least an order of magnitude greater than 3 kHz. With modem advances in MOSFETs and IGBTs, this is feasible [5].The power factor generally corrected appear purely resistive apparent power equal to real power. That is lead to, the voltage and current are become phase and the reactive power consumption to zero. This enables the most efficient delivery of electrical power from the power source to the load. Active power factor correctors can be single-stage or multi-stage. there are several types of Active power factor correctors, as shown in Figure 2.4. The most common used are:

(i) Buck

(ii) Boost

(iii) Buck-Boost

2.2.2.1 Buck Converter

A buck converter is shown in Figure 2.6. In principle, it is a combination of D diode rectifier with step down chopper with input source V_{in} . The buck converter operates off a rectified sinusoid and there are periodic dead times when the input voltage is lower than the output. During these times no power can be transferred to the output and the input current is nominally zero. S is a switch, L is the inductor, C is the capacitor and I_{out} is the output current.

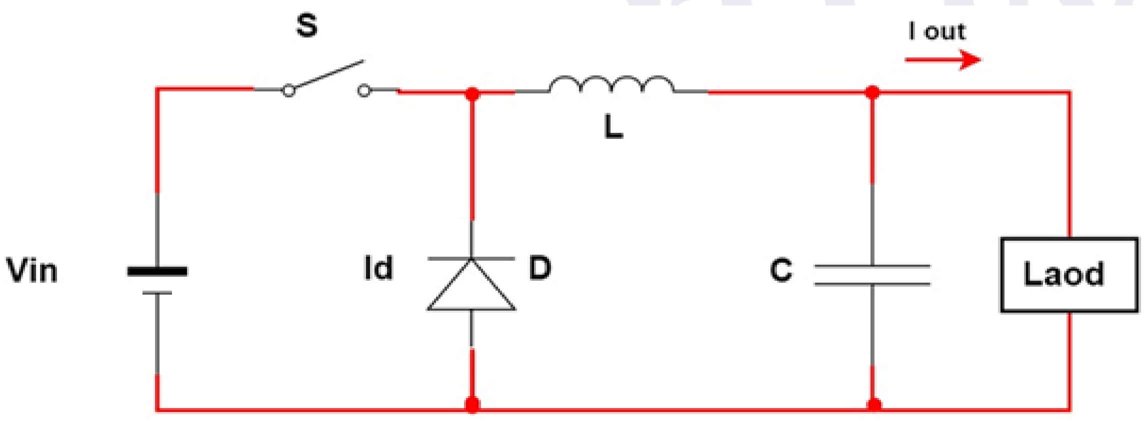

Figure 2.6: Buck Circuit

2.2.2.2 Boost Converter

One of the most common active PFC circuits is called the boost PFC converter, which is a relatively simple and low-cost circuit. A boost which is known as a converter step-up converter is a DC-to-DC power converter with an output voltage greater than its input voltage. It is a class of switched-mode power supply SMPS containing at least two semiconductor switches a diode and a transistor and at least one energy storage element, a capacitor, inductor, or the two in combination. Filters made of capacitors are normally added to the output of the converter to reduce output voltage ripple, Figure 2.7 shows the construction of the boost converter and the related components. V_{in} is the input voltage, L is input inductor, I_d the current diode and R the load resistor.

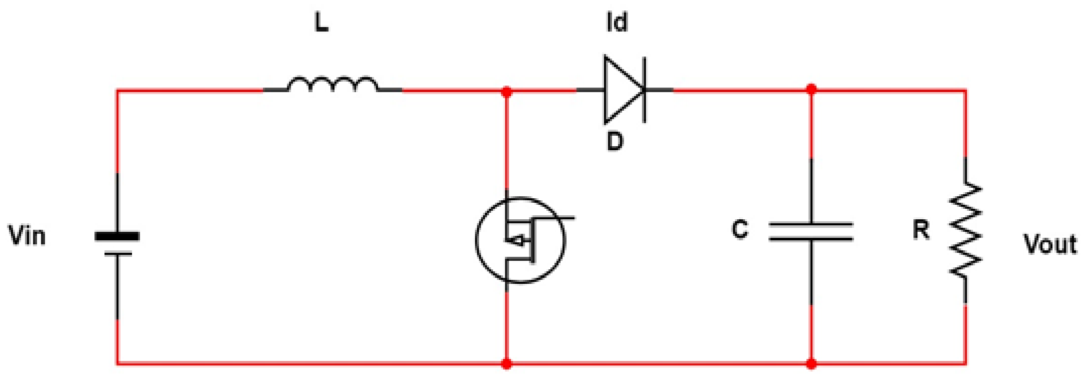

Figure 2.7: Boost Circuit

Power for the boost converter can come from any suitable DC sources, such as batteries, solar panels, rectifiers as used in this project and DC generators. A process that changes one DC voltage to a different DC voltage is called DC to DC conversion [6]. Boost converter is called a step-up converter since it steps up the source, and the power expression:

$$P = V^{*} I \tag{2.1}$$

where

$V_{in} = Input\ Voltage$

$I_{in} = Input\ Current$

$P = Power$

The output current is lower than the source current. Several features in the boost converter such as the position of the inductor on the input side reduced input current tipple and EMI (electromagnetic field), and the dc voltage gain greater than unity, make it a natural choice for active PFC application. The boost converter circuit presented in Figure 2.7, is called signal ended. This circuit more popular due to its use of a single active switch and due to the ease of driving the switch. The boost converter can be analysis into switch closed and switch open.

REFERENCES

1. Total Harmonic Distortion Reduction for Power Quality Improvement: A Review. (2017). International Journal of Science and Research (IJSR), 6(7), pp.1681-1684.
2. Ma, H., Zheng, C., Yu, W. and Lai, J. (2014). A single-stage integrated bridgeless AC/DC converter for electrolytic capacitor-less LED lighting applications. International Journal of Circuit Theory and Applications, 43(6), pp.742-755.
3. Kumar, S. and Samal, M. (2017). A New Powerfactor Correction Technique by using PFC Boost Converter. International Journal of Communication and Media Science, 4(4), pp.10-12.
4. Yao, K., Zou, C., Ye, Z. and Ruan, X. (2012). Three-phase single-switch boost power factor correction converter with high input power factor. IET Power Electronics, 5(7), pp.1095-1103.
5. Oruganti, R. and Srinivasan, R. (1997). Single phase power factor correction — A review. Sadhana, 22(6), pp.753-780.
6. Andrejevic-Stosovic, M., Dimitrijevic, M., Bojanic, S., Nieto-Taladriz, O. and Litovski, V. (2016). Characterization of nonlinear loads in power distribution grid. Facta universitatis - series: Electronics and Energetics, 29(2), pp.159-175.
7. Bouafassa, A., Rahmani, L. and Mekhilef, S. (2015). Design and real time implementation of single phase boost power factor correction converter. ISA Transactions, 55, pp.267-274.
8. Bouafassa, A., Rahmani, L. and Mekhilef, S. (2015). Design and real time implementation of single phase boost power factor correction converter. ISA Transactions, 55, pp.267-274.

9. D. Tollik and A. Pietkiewicz, “Comparative analysis of 1-phase active power factor correction topologies,” in Proc. Int. Telecommunication Energy Conf., Oct. 1992, pp. 517–523.

10. Figueiredo, J.P.M.; Tofoli, F.L.; Silva, B.L.A.; , "A review of single-phase PFC topologies based on the boost converter," Industry Applications (INDUSCON), 2010 9th IEEE/IAS International Conference on , vol., no., pp.1-6, 8-10 Nov. 2010.

11. Jangwanitlert, A.; Songboonkaew, J.; , "A Soft-Switched AC-DC Symmetrical Boost Converter with Power Factor Correction," Power Electronics and Drive Systems, 2007. PEDS '07. 7th International Conference on , vol., no., pp.784-788, 27-30 Nov. 2007.

12. M. Gopinath and D. Yogeetha, “Efficiency Analysis of Bridgeless PFC Boost Converter with the Conventional Method” International Journal of Elektronic Engineering Research, ISSN 0975 – 6450 Volume 1 Number 3 (2009) pp. 213 – 221.

13. Bhim Singh, Brig N. Singh, Ambrish Chandra, Kamal Al-Haddad, Ashish Pandey and Dwarka P. Kothari,”A Review of Single-Phase Improved Power Quality Ac-DC Converters” in IEEE Transactions on Industrial Electronic, Vol 50, No. 5, October 2003, pp. 962-981.

14. Rus, D. C., N. S. Preda, I. I. Incze, Maria Imecs, and Cs Szab. "Comparative Analysis of PWM Techniques:." IEEExplore (2010). Print.

15. Hu, Y., Liu, B. and Liu, J. (2012). PFC Controller Based on Self-Adaptive Proportional-Resonant Control. Advanced Materials Research, 588-589, pp.1533-1538.

16. S. Inverters, S. Aizam, and Z. Zarafi, “Comparison Study in Various Controllers in Single-Phase Inverters,” no. SCOReD, pp. 13–14, 2010.

17. Gawthrop, P. and Wang, L. (2000). Transfer Function and Frequency Response Estimation Using Resonant Filters. IFAC Proceedings Volumes, 33(15), pp.223-228.

18. A. Bagis, “Determination of the PID controller parameters by modified genetic algorithm for improved performance,” J. Inf. Sci. Eng., vol. 23, no. 5, pp. 1469–1480, 2007.

19. F. Bormann, “Introduction to TMS320F28335,” Creat. Commons Attrib. Licens. 3.0, pp. 1–33, 2011.

20. D. J. Ababneh and E. Y. Obeidat, “Digital Signal Processing Laboratory Using TMS320C6713 DSP Starter Kit,” 2010.